

(12)

(19)

(11)

2 319 394

(13) A

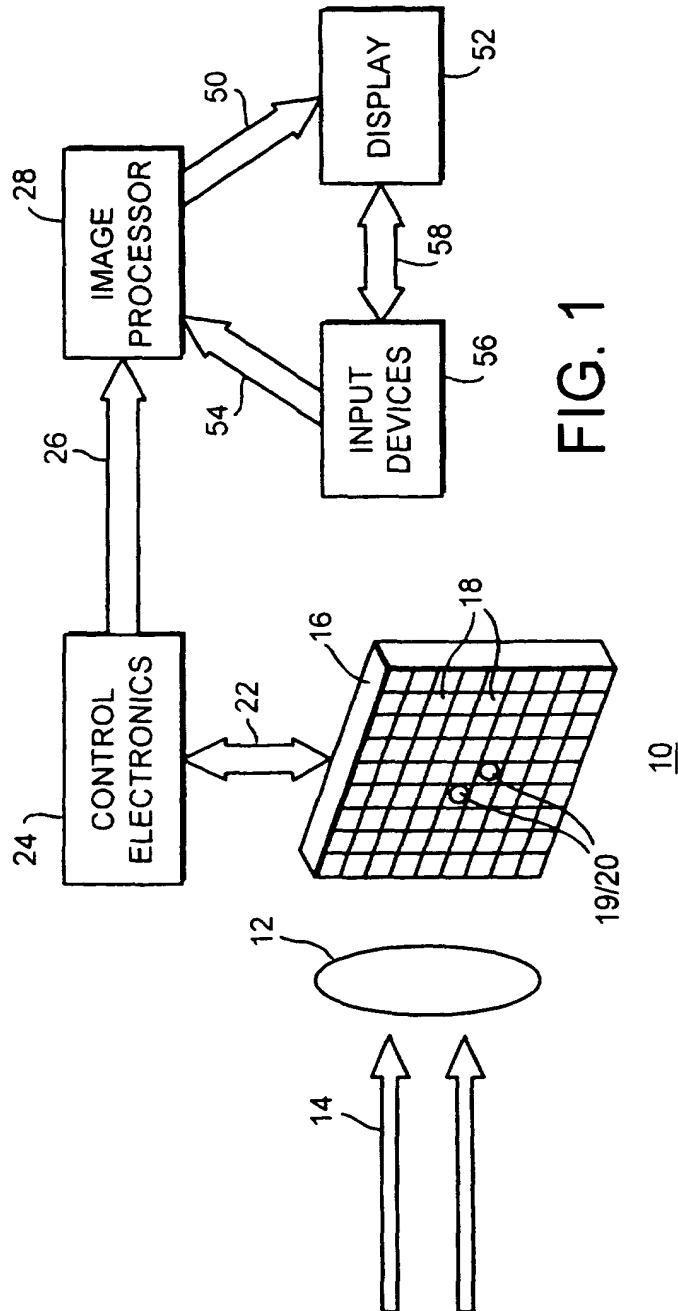


FIG. 1

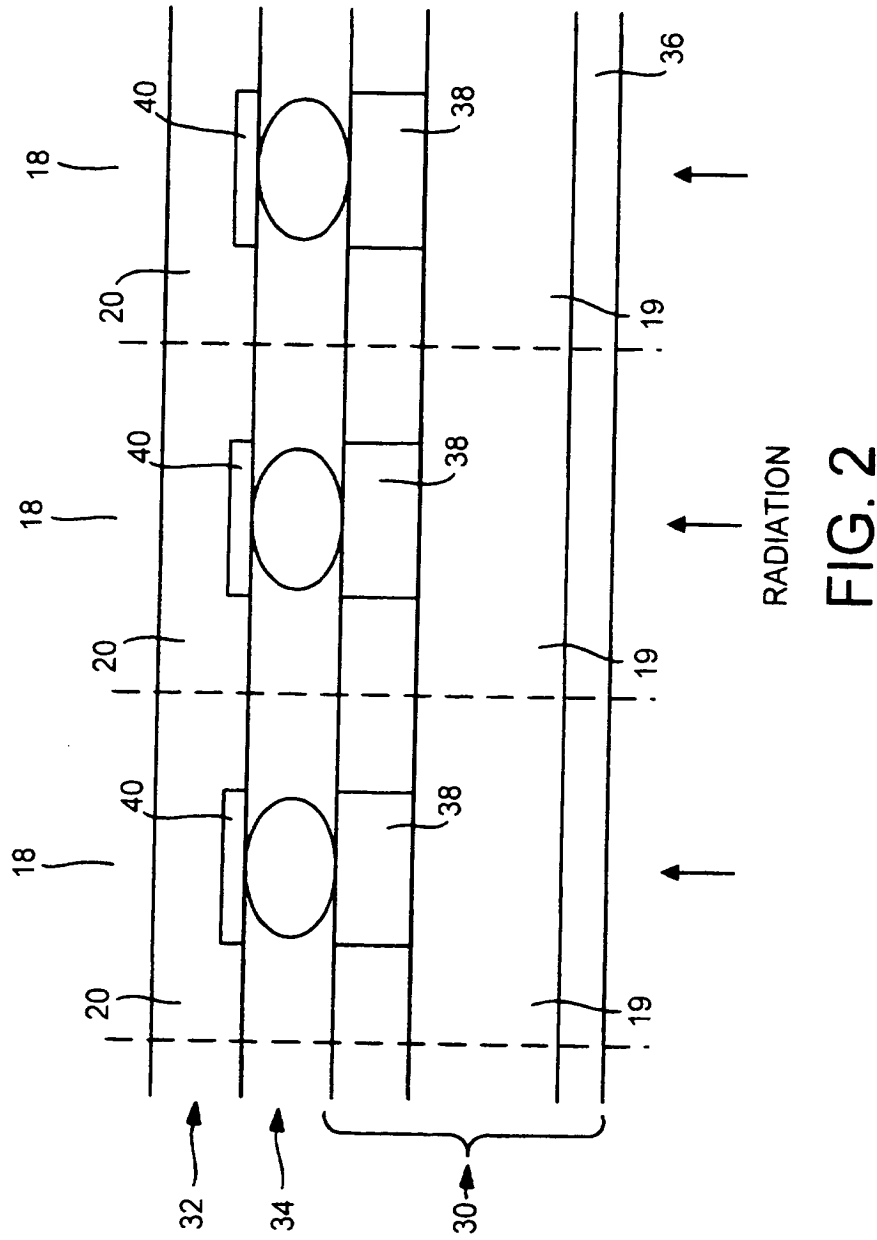
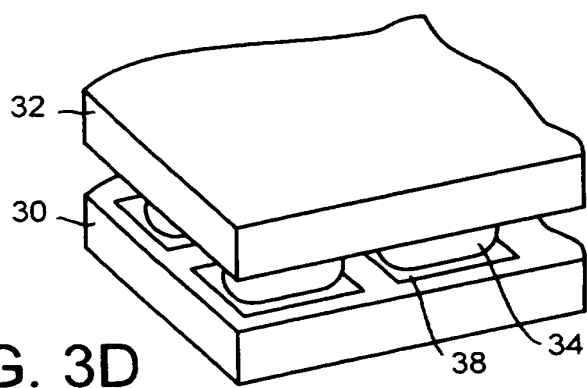
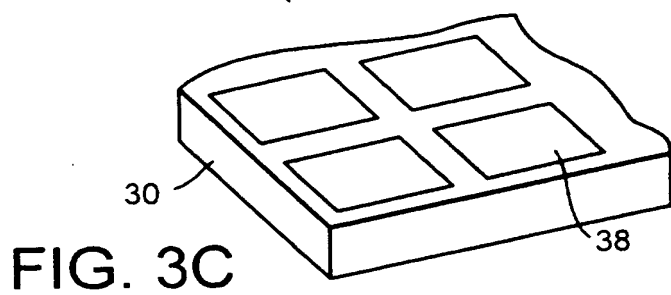
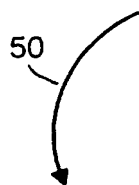
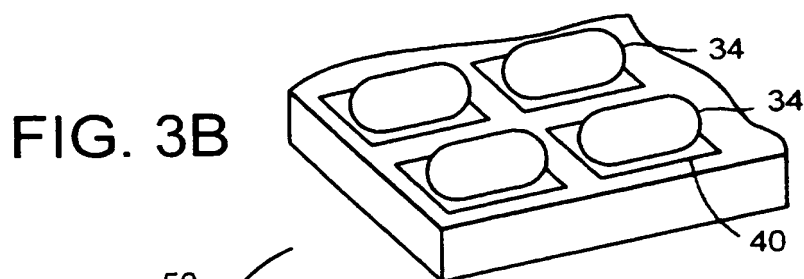
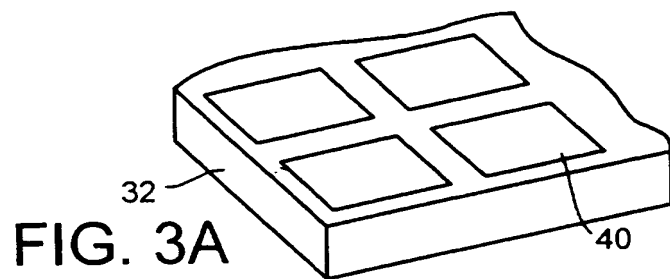


FIG. 2



BUMP-BONDED SEMICONDUCTOR IMAGING DEVICE

The invention relates to an imaging device comprising a detector substrate including a plurality of detector cells bump-bonded to a readout substrate including a corresponding plurality of readout cells and to a method of manufacturing such an imaging device.

Examples of semiconductors used for such devices are: CdZnTe, Si, CdTe, HgI₂, InSb, GaAs, Ge, TiBr, PbI₂.

A detector substrate may comprise a plurality of detector cells (e.g., pixel cells) defined by metal contacts on one side of the detector. The readout substrate can comprise a corresponding plurality of readout circuits or charge coupled device (CCD) cells. The readout substrate can be bump-bonded to the detector substrate with individual pixel cells being connected corresponding readout circuits or CCD cells by respective conductive bumps.

Imaging devices of this type can be used for medical applications involving the exposure of a patient to ionising radiation. Such applications require high radiation absorption characteristics for the detector substrate of the imaging device. Such high radiation absorption characteristics can be provided by materials using high Z elements such as CdZnTe or CdTe. Furthermore, various medical applications require high spatial resolution. For example, mammography requires the ability to observe microcalcifications which can be under 100 microns or even under 50 microns in size. The stringent requirements imposed on imaging devices require the use of small resolution elements (pixel cells), with a large arrays of such cells being needed to generate an image of a useful size.

A most important step in the fabrication of such imaging devices is the bonding of the semiconductor substrate to the readout substrate, or more precisely, the bonding of detector cells to corresponding readout cells in a one-to-one correspondence.

A semiconductor pixel imaging device is disclosed in the Applicant's International patent application WO95/33332. As mentioned in the previous paragraph, a crucial aspect of this technology is the bonding of the semiconductor substrate to the readout substrate.

Typically, prior art hybrid imaging devices such as those described in US-A-5,245,191, EP-A-0 171 135, and EP-A-0 577 187 employ indium bumps for bump-bonding a detector substrate to a readout substrate.

Indium bumps are grown on the detector metal contacts (defining the cells) and on the readout cells using evaporation. Subsequently, the two different parts are brought together, aligned, and the corresponding bumps are merged. This is also termed flip-chip joining. This cold welding technique is achieved by heating the substrates at 70-120°C and applying mechanical pressure. For detectors comprising heat sensitive materials such as cadmium zinc telluride (CdZnTe) and cadmium telluride (CdTe) the use of indium bumps is advantageous in that the process can be carried out at a low temperature. The temperatures needed for indium bump-bonding, typically 70-120°C, fall within an acceptable range for materials such as CdZnTe and CdTe.

However, during the development of imaging devices using indium bump-bonding, non-uniform detector response has been observed near the detector edges. A plausible explanation is that indium is escaping to the detector edges thus creating undesirable contact between edge metal contacts (edge pixels) and the detector edge.

The present invention seeks to mitigate the problems of the prior art.

In accordance with a first aspect of the invention, there is provided an imaging device for imaging radiation, the imaging device comprising a semiconductor substrate including an array of detector cells generating charge in response to incident radiation and a corresponding readout semiconductor substrate including an array of readout cells, each readout cell being connected to a corresponding detector cell by means of low temperature solder bumps.

An imaging device according to the invention provides improved accuracy and uniformity as a result of the bonding process employed. In particular, the method is self-aligning in that, during heating of the structure, surface tension of the melting bump forces the detector and readout substrates to align with one another.

Although the use of solder for joining circuits together is well known in the electronics arts, the normal type of solder, which is typically formed from 60 weight percent of tin (Sn) and 40 weight percent of lead (Pb), requires the use of temperatures of 183°C or more. Such temperatures, even if applied for only a short

time, damage sensitive detector substrates made of materials such as CdZnTe and CdTe.

Surprisingly, through the use of low temperature solder in accordance with the invention, the disadvantages of indium bump bonding can be avoided without causing damage to the detector substrate, even if it is made of CdZnTe or CdTe, which would be the case were conventional solder to be used.

Moreover, the use of low temperature solder avoids the need to form bumps on both the detector and readout substrates, which provides for economies of manufacture as well as improved performance and reliability. This avoids a further disadvantage of the prior art, which requires the application of indium bumps to both substrates.

Preferably the solder bumps comprise solder having a melting point under 180°C, more preferably below 100°C.

Preferably, the solder comprises an alloy of bismuth (Bi), lead (Pb) and tin (Sn).

A particularly preferred alloy which gives a low melting point of the order of 90°C, comprises approximately 52 weight percent of Bi, approximately 32 weight percent of Pb and approximately 16 weight percent Sn.

As mentioned above, preferred embodiments employ a detector substrate of CdZnTe or CdTe because of the high energy radiation absorption characteristics of those materials. However, it will be appreciated that the invention could be used with other detector substrate materials, even if they are not as temperature sensitive as CdZnTe or CdTe. The readout chip can, for example, be a CMOS chip.

The invention also provides an imaging system comprising at least one imaging device as described above.

An imaging device as described above finds particular application for medical diagnosis and/or for non-destructive testing.

In accordance with another aspect of the invention, there is provided a method of manufacturing an imaging device having an array of image cells for imaging radiation, the imaging device comprising a detector semiconductor substrate including an array of detector cells for generating charge in response to incident radiation and a readout semiconductor substrate including an array of corresponding readout cells,

the method comprising steps of: applying low temperature solder bumps to one of the substrates at positions corresponding to the image cells; aligning respective readout and detector cells to each other; and connecting the detector and readout cells by the application of heat to melt the low temperature solder bumps.

5 Preferably the solder bumps are applied to the readout substrate only, but they could alternatively or additionally be applied to the detector substrate.

 Preferably, to assist in obtaining an accurate alloy composition for the low temperature solder, and thereby to ensure an accurate melting temperature for the low temperature solder, the step of applying low temperature solder bumps comprises, in
10 successive sub-steps, applying constituent elements of the low temperature solder in required proportions at positions for the solder bumps and then applying heat to reflow the constituent elements to form the solder bumps.

 Exemplary embodiments of the invention will be described hereinafter, with reference to the accompanying drawings in which:

15 Figure 1 is a schematic overview of an imaging system for high energy radiation imaging;

 Figure 2 is a schematic cross sectional diagram of an example of imaging device in accordance with the invention; and

 Figure 3 is a schematic diagram illustrating a method of manufacturing such
20 an imaging device in accordance with invention.

 Figure 1 is a schematic representation of an example of an imaging system 10 including an embodiment of an imaging device in accordance with the invention.

 This application relates to radiation imaging of an object 12 subjected to radiation 14. The radiation may, for example, be X-ray radiation and the object 12
25 may, for example, be a part of a human body.

 The imaging device 16 comprises a plurality of pixel cells 18. The imaging device detects directly high energy incident radiation such as X-rays, γ -rays, β -rays or α -rays. The imaging device is configured on two substrates, one with an array of pixel detectors 19 and one with an array of readout circuits 20, the substrates being
30 mechanically connected to each other by low temperature solder bumps.

 Control electronics 24 includes processing and control circuitry for controlling the operation of the imaging device, or an array of imaging devices. The control

electronics 24 enables the readout circuits 20 associated with individual pixel cells 18 to be addressed (e.g., scanned) for reading out charge from the readout circuits 20 at the individual pixel cells 18. The charge read out is supplied to Analogue to Digital Converters (ADCs) for digitisation and Data Reduction Processors (DRPs) for processing the digital signal.

The processing which is performed by the DRPs can involve discriminating signals which do not satisfy certain conditions such as a minimum energy level. This is particularly useful when each readout signal corresponds to a single incident radiation event. If the energy corresponding to the measured signal is less than that to be expected for the radiation used, it can be concluded that the reduced charge value stored results from scattering effects. In such a case the measurement can be discarded with a resulting improvement in image resolution.

The control electronics 24 is further interfaced via a path represented schematically by the arrow 26 to an image processor 28. The image processor 28 includes data storage in which it stores digital values representative of the charge values read from each pixel cell along with the position of the pixel cell 18 concerned. The image processor 28 builds up an image for display. It then reads the values stored for the selected pixel positions to cause a representation of the data to be displayed on a display 32 via a path represented schematically by the arrow 30. The data can of course be printed rather than, or in addition to being displayed and can be subjected to further processing operations. Input devices 36, for example a keyboard and/or other typical computer input devices, are provided for controlling the image processor 28 and the display 32 as represented by the arrows 34 and 38.

Figure 2 is a schematic cross section of part of an imaging device 16. In this example, the imaging device 16 comprises an image detector substrate 30 connected to an image circuit substrate 32 by means of solder bumps 34. A pixel detector 19 of each pixel cell 18 is defined on the detector substrate 30 by a continuous electrode 36 which applies a biasing voltage and pixel location electrodes (contact pads) 38 to define a detection zone for the pixel cell 18. Corresponding pixel circuits 20 on the image circuit substrate 32 are defined at locations corresponding to the electrodes 38 (ie to the pixel detectors 19). Electrodes (contact pads) 40 for the pixel circuits 20 are electrically connected to the corresponding electrodes 38 by the solder bumps 34.

In this manner, when charge is generated in a pixel detector 19 in response to incident radiation, this charge is passed via the solder bumps 34 to the corresponding pixel circuit 20.

Thus, each pixel cell 18 of the imaging device 16 is in effect defined on the substrate by electrodes (not shown) which apply a biasing voltage to define a detection zone (i.e., the pixel detector 19) for the pixel cell 18. Corresponding readout circuits on the readout substrate can comprise, for example, active pixel circuits 20 as described in WO95/33332. The pixel detectors 19 are formed with a detection zone such that, when a photon is photo-absorbed in the semiconductor substrate 16 at a pixel cell 18 creating an electric charge or when a charged radiation ionizes the detection zone of the semiconductor substrate 16 at a pixel cell 18, an electric pulse flows from the semiconductor substrate detection zone to the readout circuit 20 for that pixel cell 18 through the solder bump 34 for that pixel cell.

In order to provide efficient charge absorption for X-rays and other high energy radiation typically having energies in excess of 1keV, the use of high absorption semiconductor materials for the detector substrate is desirable, for example, CdZnTe or CdTe. In this case, low temperature processes used during manufacture avoid damaging the temperature sensitive substrate.

Thus, through the use of low temperature soldering (under 180°C) sensitive materials such as CdZnTe or CdTe can be used without impairing the characteristics of the detector substrate.

An example of an imaging device in accordance with the invention, therefore comprises a semiconductor substrate and a readout substrate, the substrates comprising detecting and readout cells respectively, each detecting cell being connected to a corresponding (one-to-one correspondence) readout cell with low temperature solder bumps.

By way of example, monolithic detectors of dimensions 12.2x4.2 mm² (41,000 pixels of 35 microns size) and 18.9x9.6 mm² (130,000 pixels of 35 microns size) connected to a CMOS chip via low temperature solder bumps may be constructed. However, the actual size of the pixel circuit and the pixel detector will depend on the application for which the imaging device is intended, and the circuit technology used.

Such an imaging device will then exhibit the necessary uniform performance

over a large number of bonded cells thus meeting the criteria (high absorption efficiency, high spatial resolution) for use in medical diagnosis, for example mammography, dental imaging, chest X-rays, conventional X-rays, fluoroscopy, computerised tomography, nuclear medicine and non-destructive testing.

5 Low temperature solder bumps may be as small as 5 microns in diameter but may be larger. A soldering material with low melting point will be a suitable low temperature solder. By a low temperature solder is meant a solder which can be melted at a temperature which will mitigate or prevent damage or deterioration of a temperature sensitive detector substrate such as CdZnTe or CdTe. A low temperature
10 solder has a melting point of preferably less than 180°C, more preferably less than 120°C and yet more preferably less than 100°C. A suitable example of such a low temperature solder material is a ternary bismuth-lead-tin (BiPbSn) alloy. The melting point of a eutectic (52wt% Bi, 32wt% Pb, 16wt% Sn) alloy is, for example, under 100°C at about 90°C. The percentages of the composition are each approximate. The
15 alloy may be made solely of the three elements mentioned in approximately the proportions indicated to a total of 100wt%. However, the alloy composition may be varied to optimise wetting, melting point and/or thermal expansion on solidification. For example, the proportions of the component elements may be varied and/or other component elements may be chosen for addition to or substitution for the elements
20 mentioned.

Figure 3 is a schematic representation of a method of manufacturing an imaging device as described above.

Figure 3A represents a step of providing a readout substrate 32 with an array of contact pads 40 for connections to corresponding contact pads 38 on a detector
25 substrate 30 (Figure 3C).

Figure 3A represents the provision of solder bumps 34 on the contact pads 40. The solder bumps can be formed, for example, by vacuum evaporation or electroplating for depositing the metal alloy solder material on respective contact pads. A metal or photoresist mask may be used. To attain an accurate alloy
30 composition, each constituent metal may be deposited separately but then, prior to joining, the structure is subjected to a process step in which the bumps are reflowed, (subjected to a temperature higher than the alloy's melting point) thus homogenising

the bump composition at each contact pad position. It is not necessary to exceed significantly the melting point of the alloy, in order to reflow the layered "sandwich" structure.

5 In a preferred embodiment of the invention, the bump is deposited on the readout chip side only as shown in Figure 3B so as to spare the detector from any harmful deposition and for economy of tasks (avoiding growing bumps on the detector substrate).

Alternatively, task economy could also be achieved by depositing the solder bumps 34 on the detector substrate 30 (Figure 3C) instead, although this would
10 increase the risk of possible damage to the detector substrate.

As a further alternative, bumps can be grown on both the readout substrate 32 and on the detector substrate 30 if a suitable bump volume cannot be attained otherwise.

A solderable (solder wettable) pad can be formed underneath the solder bump.
15 This pad can be deposited prior to bump deposition using the same mask. It is not necessary to use the same technique for depositing both the bump and the under-bump metallurgy. An additional advantage provided by low temperature solder is that it allows for thinner under-bump metallurgies, as well as providing the choice of using otherwise unusable metals, as the rate at which the under-bump metallurgy dissolves
20 into the bump is proportional to temperature.

Guard rings, also made of solder, and in addition to their electrical function, may be used around the pixel array hermetically to seal the pixel area solder joints from external atmosphere. Dams and/or shields, for electrical and/or mechanical purposes, may also be constructed.

25 The bumps need not all be of the same size. A small number of relatively large bumps may be used to aid the self-alignment of the main pixel array with a large number of relatively small bumps.

Once the solder bumps are formed, then the readout substrate 34 (Figure 3B) is flip-chip joined to the detector substrate (Figure 3C), as represented by the arrow
30 50 with the controlled application of heat at a temperature and for a time sufficient to melt the solder bumps, but not sufficient to cause damage to the semiconductor substrates. In this manner joining of the respective contact pads 38, 40 on the

detector substrate 30 and the readout substrate 32, respectively, can be achieved.

Figure 3D represents one corner of the joined hybrid imaging device 16.

Thus there has been described a semiconductor imaging device, for use for example in medical diagnosis and non-destructive testing, which includes a radiation
5 detector semiconductor substrate and a readout substrate connected to the detector by means of low temperature solder bumps. A low temperature solder should have a melting point under about 180°C, preferably less than 150°C, more preferably less than 120°C and yet more preferably less than 100°C. Good examples of such low
10 temperature solders are provided by bismuth-based alloys, for example the eutectic alloy, which is composed of approximately 52wt% Bi, approximately 32wt% Pb and approximately 16wt% Sn to 100wt% and has a melting point under 100°C.

An example of an imaging device in accordance with the invention can be used in applications such as medical diagnosis, for example for mammography, dental imaging, chest X-rays, fluoroscopy, computerised tomography, nuclear medicine and
15 so on. An example of an imaging device in accordance with the invention can also be used in applications such as non-destructive testing.

Although particular embodiments of the invention, have been described, it will be appreciated that modifications and or additions thereto can be made within the scope of the invention.

CLAIMS

1. An imaging device for imaging radiation, said imaging device comprising a semiconductor substrate including an array of detector cells for generating charge in response to incident radiation and a corresponding readout semiconductor substrate including an array of readout cells, each readout cell being connected to a corresponding detector cell by means of low temperature solder bumps.
2. An imaging device according to Claim 1, where said solder bumps comprise solder having a melting point under 180°C.
3. An imaging device according to Claim 2, wherein said solder has a melting point under 100°C.
4. An imaging device according to any preceding Claim, wherein said solder comprises a BiPbSn alloy.
5. An imaging device according to Claim 4, wherein said solder comprises an alloy of approximately 52 weight percent of Bi, approximately 32 weight percent of Pb and approximately 16 weight percent Sn.
6. An imaging device according to any one of the preceding Claims, wherein said detector substrate comprises CdZnTe or CdTe.
7. A imaging system comprising at least one imaging device according to any preceding Claim.
8. The use of an imaging device according to any one of Claims 1 to 6 for medical diagnosis.
9. The use of an imaging device according to any one of Claims 1 to 6 for non-destructive testing.

10. A method of manufacturing an imaging device having an array of image cells for imaging radiation, said imaging device comprising a detector semiconductor substrate including an array of detector cells for generating charge in response to incident radiation and a readout semiconductor substrate including an array of
5 corresponding readout cells, said method comprising steps of:
- applying low temperature solder bumps to one of said substrates at positions corresponding to said image cells;
 - aligning respective readout and detector cells to each other; and
 - connecting said detector and readout cells by the application of heat to melt
10 said low temperature solder bumps.
11. A method according to Claim 10, wherein said solder bumps are applied to said readout substrate at positions corresponding to said readout cells.
- 15 12. A method according to Claim 10, wherein said solder bumps are applied to said readout substrate at positions corresponding to said readout cells and to said detector substrate at positions corresponding to said detector cells.
13. A method according to any one of Claims 10 to 12, wherein said temperature
20 is low enough to prevent damage to said detector substrate during said application of said heat.
14. A method according to Claim 13, where said solder bumps comprise solder having a melting point under 180°C.
- 25 15. A method according to Claim 13, wherein said solder has a melting point under 100°C.
16. A method according to any one of Claims 10 to 15, wherein said solder
30 comprises a BiPbSn alloy.
17. A method according to Claim 16, wherein said solder comprises an alloy of

approximately 52 weight percent of Bi, approximately 32 weight percent of Pb and approximately 16 weight percent Sn.

18. A method according to Claim 16 or Claim 17, wherein said step of applying
5 low temperature solder bumps comprises, in successive sub-steps, applying constituent elements of said low temperature solder in required proportions at positions for said solder bumps and then applying heat to reflow said constituent elements to form said solder bumps.

10 19. An imaging device substantially as hereinbefore described with reference to the accompanying drawings.

20. An imaging system substantially as hereinbefore described with reference to the accompanying drawings.

15

21. A method of manufacturing an imaging device substantially as hereinbefore described with reference to the accompanying drawings.



The
Patent
Office
13

Application No: GB 9626972.5
Claims searched: all

Examiner: Martyn Dixon
Date of search: 18 August 1997

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): H1K (KEBA,KECB,KECCX,KECD,KECX,KPAC,KRG)

Int Cl (Ed.6): H01L (21/60,31/00,31/02,31/0224,31/115,31/117,31/118,31/119);
G01T (1/29)

Other: Online: WPI, JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
X	WO 93/04384 A (General Imaging) see fig 7 and page 11, lines 1 <i>et seq</i>	1,7,10,11
X	EP 0415541 A (Shimadzu) see col 4, lines 3-10 and col 5, lines 31-53	1,6,7,10,11,13
X,E	JP 090083007 A (Shimadzu) see WPI Abstract Accession No 97-251537/199723	1,7,9,10
X,E	JP 090036410 A (Shimadzu) see WPI Abstract Accession No 97-171828/199716	1,7,10
X	Patent Abstracts of Japan [P-842], Vol 13, No 104 & JP630284485A (Shimadzu)	1,7,10

X Document indicating lack of novelty or inventive step
Y Document indicating lack of inventive step if combined with one or more other documents of same category.
& Member of the same patent family

A Document indicating technological background and/or state of the art.
P Document published on or after the declared priority date but before the filing date of this invention.
E Patent document published on or after, but with priority date earlier than, the filing date of this application.



1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100
101
102
103
104
105
106
107
108
109
110
111
112
113
114
115
116
117
118
119
120
121
122
123
124
125
126
127
128
129
130
131
132
133
134
135
136
137
138
139
140
141
142
143
144
145
146
147
148
149
150
151
152
153
154
155
156
157
158
159
160
161
162
163
164
165
166
167
168
169
170
171
172
173
174
175
176
177
178
179
180
181
182
183
184
185
186
187
188
189
190
191
192
193
194
195
196
197
198
199
200
201
202
203
204
205
206
207
208
209
210
211
212
213
214
215
216
217
218
219
220
221
222
223
224
225
226
227
228
229
230
231
232
233
234
235
236
237
238
239
240
241
242
243
244
245
246
247
248
249
250
251
252
253
254
255
256
257
258
259
260
261
262
263
264
265
266
267
268
269
270
271
272
273
274
275
276
277
278
279
280
281
282
283
284
285
286
287
288
289
290
291
292
293
294
295
296
297
298
299
300
301
302
303
304
305
306
307
308
309
310
311
312
313
314
315
316
317
318
319
320
321
322
323
324
325
326
327
328
329
330
331
332
333
334
335
336
337
338
339
340
341
342
343
344
345
346
347
348
349
350
351
352
353
354
355
356
357
358
359
360
361
362
363
364
365
366
367
368
369
370
371
372
373
374
375
376
377
378
379
380
381
382
383
384
385
386
387
388
389
390
391
392
393
394
395
396
397
398
399
400
401
402
403
404
405
406
407
408
409
410
411
412
413
414
415
416
417
418
419
420
421
422
423
424
425
426
427
428
429
430
431
432
433
434
435
436
437
438
439
440
441
442
443
444
445
446
447
448
449
450
451
452
453
454
455
456
457
458
459
460
461
462
463
464
465
466
467
468
469
470
471
472
473
474
475
476
477
478
479
480
481
482
483
484
485
486
487
488
489
490
491
492
493
494
495
496
497
498
499
500
501
502
503
504
505
506
507
508
509
510
511
512
513
514
515
516
517
518
519
520
521
522
523
524
525
526
527
528
529
530
531
532
533
534
535
536
537
538
539
540
541
542
543
544
545
546
547
548
549
550
551
552
553
554
555
556
557
558
559
560
561
562
563
564
565
566
567
568
569
570
571
572
573
574
575
576
577
578
579
580
581
582
583
584
585
586
587
588
589
590
591
592
593
594
595
596
597
598
599
600
601
602
603
604
605
606
607
608
609
610
611
612
613
614
615
616
617
618
619
620
621
622
623
624
625
626
627
628
629
630
631
632
633
634
635
636
637
638
639
640
641
642
643
644
645
646
647
648
649
650
651
652
653
654
655
656
657
658
659
660
661
662
663
664
665
666
667
668
669
670
671
672
673
674
675
676
677
678
679
680
681
682
683
684
685
686
687
688
689
690
691
692
693
694
695
696
697
698
699
700
701
702
703
704
705
706
707
708
709
710
711
712
713
714
715
716
717
718
719
720
721
722
723
724
725
726
727
728
729
730
731
732
733
734
735
736
737
738
739
740
741
742
743
744
745
746
747
748
749
750
751
752
753
754
755
756
757
758
759
760
761
762
763
764
765
766
767
768
769
770
771
772
773
774
775
776
777
778
779
780
781
782
783
784
785
786
787
788
789
790
791
792
793
794
795
796
797
798
799
800
801
802
803
804
805
806
807
808
809
810
811
812
813
814
815
816
817
818
819
820
821
822
823
824
825
826
827
828
829
830
831
832
833
834
835
836
837
838
839
840
841
842
843
844
845
846
847
848
849
850
851
852
853
854
855
856
857
858
859
860
861
862
863
864
865
866
867
868
869
870
871
872
873
874
875
876
877
878
879
880
881
882
883
884
885
886
887
888
889
890
891
892
893
894
895
896
897
898
899
900
901
902
903
904
905
906
907
908
909
910
911
912
913
914
915
916
917
918
919
920
921
922
923
924
925
926
927
928
929
930
931
932
933
934
935
936
937
938
939
940
941
942
943
944
945
946
947
948
949
950
951
952
953
954
955
956
957
958
959
960
961
962
963
964
965
966
967
968
969
970
971
972
973
974
975
976
977
978
979
980
981
982
983
984
985
986
987
988
989
990
991
992
993
994
995
996
997
998
999
1000
1001
1002
1003
1004
1005
1006
1007
1008
1009
1010
1011
1012
1013
1014
1015
1016
1017
1018
1019
1020
1021
1022
1023
1024
1025
1026
1027
1028
1029
1030
1031
1032
1033
1034
1035
1036
1037
1038
1039
1040
1041
1042
1043
1044
1045
1046
1047
1048
1049
1050
1051
1052
1053
1054
1055
1056
1057
1058
1059
1060
1061
1062
1063
1064
1065
1066
1067
1068
1069
1070
1071
1072
1073
1074
1075
1076
1077
1078
1079
1080
1081
1082
1083
1084
1085
1086
1087
1088
1089
1090
1091
1092
1093
1094
1095
1096
1097
1098
1099
1100
1101
1102
1103
1104
1105
1106
1107
1108
1109
1110
1111
1112
1113
1114
1115
1116
1117
1118
1119
1120
1121
1122
1123
1124
1125
1126
1127
1128
1129
1130
1131
1132
1133
1134
1135
1136
1137
1138
1139
1140
1141
1142
1143
1144
1145
1146
1147
1148
1149
1150
1151
1152
1153
1154
1155
1156
1157
1158
1159
1160
1161
1162
1163
1164
1165
1166
1167
1168
1169
1170
1171
1172
1173
1174
1175
1176
1177
1178
1179
1180
1181
1182
1183
1184
1185
1186
1187
1188
1189
1190
1191
1192
1193
1194
1195
1196
1197
1198
1199
1200
1201
1202
1203
1204
1205
1206
1207
1208
1209
1210
1211
1212
1213
1214
1215
1216
1217
1218
1219
1220
1221
1222
1223
1224
1225
1226
1227
1228
1229
1230
1231
1232
1233
1234
1235
1236
1237
1238
1239
1240
1241
1242
1243
1244
1245
1246
1247
1248
1249
1250
1251
1252
1253
1254
1255
1256
1257
1258
1259
1260
1261
1262
1263
1264
1265
1266
1267
1268
1269
1270
1271
1272
1273
1274
1275
1276
1277
1278
1279
1280
1281
1282
1283
1284
1285
1286
1287
1288
1289
1290
1291
1292
1293
1294
1295
1296
1297
1298
1299
1300
1301
1302
1303
1304
1305
1306
1307
1308
1309
1310
1311
1312
1313
1314
1315
1316
1317
1318
1319
1320
1321
1322
1323
1324
1325
1326
1327
1328
1329
1330
1331
1332
1333
1334
1335
1336
1337
1338
1339
1340
1341
1342
1343
1344
1345
1346
1347
1348
1349
1350
1351
1352
1353
1354
1355
1356
1357
1358
1359
1360
1361
1362
1363
1364
1365
1366
1367
1368
1369
1370
1371
1372
1373
1374
1375
1376
1377
1378
1379
1380
1381
1382
1383
1384
1385
1386
1387
1388
1389
1390
1391
1392
1393
1394
1395
1396
1397
1398
1399
1400
1401
1402
1403
1404
1405
1406
1407
1408
1409
1410
1411
1412
1413
1414
1415
1416
1417
1418
1419
1420
1421
1422
1423
1424
1425
1426
1427
1428
1429
1430
1431
1432
1433
1434
1435
1436
1437
1438
1439
1440
1441
1442
1443
1444
1445
1446
1447
1448
1449
1450
1451
1452
1453
1454
1455
1456
1457
1458
1459
1460
1461
1462
1463
1464
1465
1466
1467
1468
1469
1470
1471
1472
1473
1474
1475
1476
1477
1478
1479
1480
1481
1482
1483
1484
1485
1486
1487
1488
1489
1490
1491
1492
1493
1494
1495
1496
1497
1498
1499
1500
1501
1502
1503
1504
1505
1506
1507
1508
1509
1510
1511
1512
1513
1514
1515
1516
1517
1518
1519
1520
1521
1522
1523
1524
1525
1526
1527
1528
1529
1530
1531
1532
1533
1534
1535
1536
1537
1538
1539
1540
1541
1542
1543
1544
1545
1546
1547
1548
1549
1550
1551
1552
1553
1554
1555
1556
1557
1558
1559
1560
1561
1562
1563
1564
1565
1566
1567
1568
1569
1570
1571
1572
1573
1574
1575
1576
1577
1578
1579
1580
1581
1582
1583
1584
1585
1586
1587
1588
1589
1590
1591
1592
1593
1594
1595
1596
1597
1598
1599
1600
1601
1602
1603
1604
1605
1606
1607
1608
1609
1610
1611
1612
1613
1614
1615
1616
1617
1618
1619
1620
1621
1622
1623
1624
1625
1626
1627
1628
1629
1630
1631
1632
1633
1634
1635
1636
1637
1638
1639
1640
1641
1642
1643
1644
1645
1646
1647
1648
1649
1650
1651
1652
1653
1654
1655
1656
1657
1658
1659
1660
1661
1662
1663
1664
1665
1666
1667
1668
1669
1670
1671
1672
1673
1674
1675
1676
1677
1678
1679
1680
1681
1682
1683
1684
1685
1686
1687
1688
1689
1690
1691
1692
1693
1694
1695
1696
1697
1698
1699
1700
1701
1702
1703
1704
1705
1706
1707
1708
1709
1710
1711
1712
1713
1714
1715
1716
1717
1718
1719
1720
1721
1722
1723
1724
1725
1726
1727
1728
1729
1730
1731
1732
1733
1734
1735
1736
1737
1738
1739
1740
1741
1742
1743
1744
1745
1746
1747
1748
1749
1750
1751
1752
1753
1754
1755
1756
1757
1758
1759
1760
1761
1762
1763
1764
1765
1766
1767
1768
1769
1770
1771
1772
1773
1774
1775
1776
1777
1778
1779
1780
1781
1782
1783
1784
1785
1786
1787
1788
1789
1790
1791
1792
1793
1794
1795
1796
1797
1798
1799
1800
1801
1802
1803
1804
1805
1806
1807
1808
1809
1810
1811
1812
1813
1814
1815
1816
1817
1818
1819
1820
1821
1822
1823
1824
1825
1826
1827
1828
1829
1830
1831
1832
1833
1834
1835
1836
1837
1838
1839
1840
1841
1842
1843
1844
1845
1846
1847
1848
1849
1850
1851
1852
1853
1854
1855
1856
1857
1858
1859
1860
1861
1862
1863
1864
1865
1866
1867
1868
1869
1870
1871
1872
1873
1874
1875
1876
1877
1878
1879
1880
1881
1882
1883
1884
1885
1886
1887
1888
1889
1890
1891
1892
1893
1894
1895
1896
1897
1898
1899
1900
1901
1902
1903
1904
1905
1906
1907
1908
1909
1910
1911
1912
1913
1914
1915
1916
1917
1918
1919
1920
1921
1922
1923
1924
1925
1926
1927
1928
1929
1930
1931
1932
1933
1934
1935
1936
1937
1938
1939
1940
1941
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034
2035
2036
2037
2038
2039
2040
2041
2042
2043
2044
2045
2046
2047
2048
2049
2050
2051
2052
2053
2054
2055
2056
2057
2058
2059
2060
2061
2062
2063
2064
2065
2066
2067
2068
2069
2070
2071
2072
2073
2074
2075
2076
2077
2078
2079
2080
2081
2082
2083
2084
2085
2086
2087
2088
2089
2090
2091
2092
2093
2094
2095
2096
2097
2098
2099
2100
2101
2102
2103
2104
2105
2106
2107
2108
2109
2110
2111
2112
2113
2114
2115
2116
2117
2118
2119
2120
2121
2122
2123
2124
2125
2126
2127
2128
2129
2130
2131
2132
2133
2134
2135
2136
2137
2138
2139
2140
2141
2142
2143
2144
2145
2146
2147
2148
2149
2150
2151
2152
2153
2154
2155
2156
2157
2158
2159
2160
2161
2162
2163
2164
2165
2166
2167
2168
2169
2170
2171
2172
2173
2174
2175
2176
2177
2178
2179
2180
2181
2182
2183
2184
2185
2186
2187
2188
2189
2190
2191
2192
2193
2194
2195
2196
2197
2198
2199
2200
2201
2202
2203
2204
2205
2206
2207
2208
2209
2210
2211
2212
2213
2214
2215
2216
2217
2218
2219
2220
2221
2222
2223
2224
2225
2226
222